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The Solution of Cold Neutron Source using Solid Methane Moderator for the CPHS

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Abstract

The Compact Pulsed Hadron Source (CPHS) at Tsinghua University will produce neutrons by bombarding a 13-MeV proton beam from a LINAC system on a beryllium target. One of the purposes of this neutron source is to provide the neutron facilities for characterization of advanced materials with an emphasis on soft matter and biological systems, for which high cold-neutron fluxes are essential. The design and optimization of the solid-methane moderator system aim at the enhancement of cold neutron production. This paper describes the moderator configuration, the associated gas-handling and cryogenic apparatus, and the operation procedure.

Keywords: cold neutron source, solid methane moderator, pulsed neutron source;

1. Main text

The Compact Pulsed Hadron Source (CPHS) currently under construction at Tsinghua University will provide a platform of neutron facilities for education, basic research and instrumentation development. Proton bursts accelerated to 13 MeV at a repetition rate of 50Hz by the linear accelerators strike a thin beryllium target, producing neutrons over the 0.1-10 MeV energy range. These fast neutrons are slowed down by a moderator-reflector system to maximize the yield of thermal and cold neutrons (wavelengths

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ranging from 1 to >10 Å) that are required for materials characterization. Two neutron beam lines, a small angle neutron scattering (SANS) instrument and a neutron imaging & radiography station, are to be installed initially [1]. Both instruments will benefit from having a high flux of cold neutrons (wavelengths > 4 Å). A fast neutron loses its energy rapidly due to multiple scattering by hydrogen atoms in a cold moderator. Generally speaking, the lower the temperature of the moderator is realized, the lower the peak energy of the neutron spectrum extracted from the cold moderator is obtained [2]. Solid methane is proven to be one of the most effective cold moderators, because it has a high hydrogen density and the excitation levels of solid methane contains a number of low-energy rotational and vibrational modes that facilitate further energy loss of the neutrons[3,4]. In a very high radiation environment radiolysis of solid methane should be considered and dealt with carefully, however, such effect is not expected to impose a problem for the operation of low-power neutron sources such as the Low Energy Neutron Source (LENS) of Indiana University, USA or the CPHS.

When no special absorption material is inserted into the moderator system to prevent the neutrons below a certain cutoff energy from re-entering into the cold moderator, the cold moderator is called ‘coupled’ with the target-reflector environment. A coupled moderator tends to emit higher neutron fluxes with a wider pulse width. On some occasions in the interest of maintaining a narrow neutron pulse, which is essential to high energy-resolution measurements, a ‘decoupled’ moderator is preferred. The CPHS is a long-pulse neutron source because of the broad proton pulse width (~0.5 ms) inherent in the proton linac operation. Consequently, the CPHS employs a coupled neutron moderator. Conveniently, such wide neutron widths do not cause detrimental effects to the SANS and imaging instruments. Throughout the design and engineering of the target-moderator-reflector (TMR) system, we refer broadly to the experiences of the LENS. More details regarding the TMR design and performance are given in an accompanying paper in this Proceedings [5].

2. Cryogenic Moderator

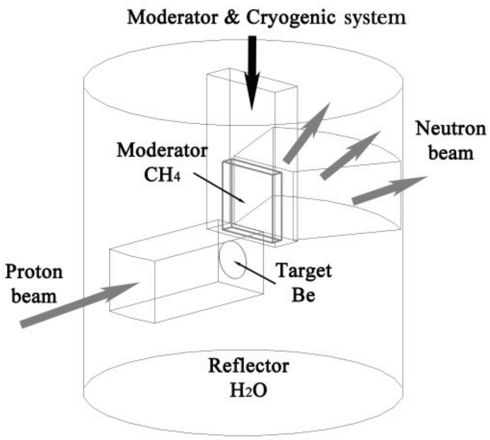

Fig. 1. A schematic layout of the target-reflector-moderator (TRM) assembly.

The configuration of the Be target, methane moderator, and the water-filled reflector is shown in Fig. 1. This configuration allows the re-entry of the forward-going high-energy neutrons into the moderator medium through back-reflection from the surrounding water hence enhancing the cold-neutron flux. The cryogenic moderator assembly is inserted vertically into the cavity in the reflector from the top. The bottom surface of an aluminum moderator cell is connected to the 2nd stage cold plate of a close-cycle helium refrigerator (from Cryomech Ltd. USA) via an aluminum bar whose high thermal conductivity is ensured by the very high (99.999%) purity, as shown in Fig. 2 schematically. A similar configuration for a solid methane moderator has been successfully installed in LENS [6]. Such lifting of the refrigerator stem and cold head position above from the strong radiation field at the direct-beam level, aided by the polyethylene shield plug, alleviates radiation-activation of the cryogenic components. Methane is to be transported into or out the moderator cell through a filling/releasing tubing that enters the vacuum vessel from the top and connects to the top end of the moderator cell. Small heaters and thermal sensors are anchored along the heat-conducting path for temperature monitoring and control. The temperature controller is not shown.

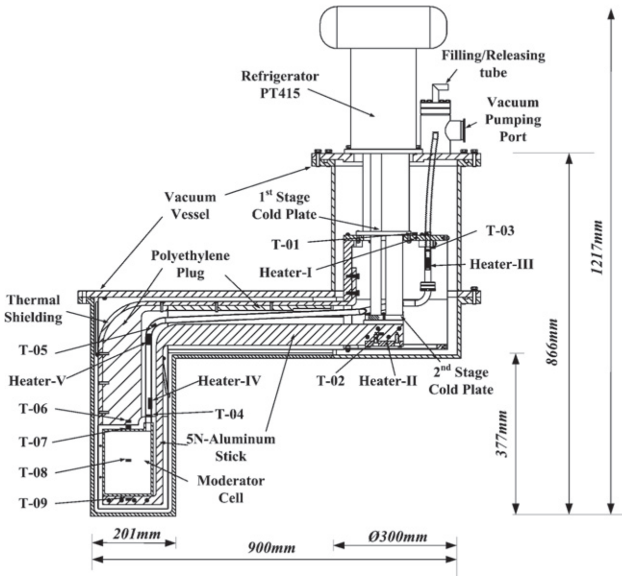

Fig. 2. A schematic diagram showing the moderator cell, the cold head of the helium refrigerator, and the connecting bar made of high-purity aluminum. Other components are described in the text.

3. Operation

The total heat load of the cold moderator system is estimated to be about 1 watt at 5K. The helium refrigerator provides the cooling capacity for the moderator in two stages: the first stage of ~40W at 45K and the second ~1.5W at 4K. A schematic of the gas-handling system that is responsible for the transfer and release of methane gas in conjunction with various safety controls is shown in Fig. 3a. Compressed-gas cylinders, supply and release tanks, transport lines, valves and pressure gauges, pumps, etc., all industrially graded to handle flammable gases, are shown. Prior to an operation the entire system is leak tested, purged by helium gas, and pumped out. Methane gas is first introduced into the supply tank (180 liters in volume) at about 1000 Torr. The gas is then fed into the moderator cell that is cooled to an intermediate temperature so that the methane gas is first condensed into liquid, filling the cell upward from the bottom. After the cell is full, the temperature is reduced so that the liquid is solidified and maintained stably at the lowest achievable temperature. During the condensation and solidification process the transport line is heated above the melting point of methane to avoid blockage of the line. From the known volumes of the containers and the monitored pressures and temperatures, the amount of methane in the moderator during the filling process can be determined accurately using the ideal gas law. Radiolysis of the methane molecules in the solid state is known to generate energized defects, a lengthy accumulation of these defects must eventually be released for preventing a structural damage of the moderator cell [7, 8]. Although the relatively low dosage level from the CPHS target is expected not to cause such radiolysis problem, the moderator system allows a programmed warm-up of the solid methane to ~65K, when it is necessary, for the release of the stored energy before it reaches a concerned level.

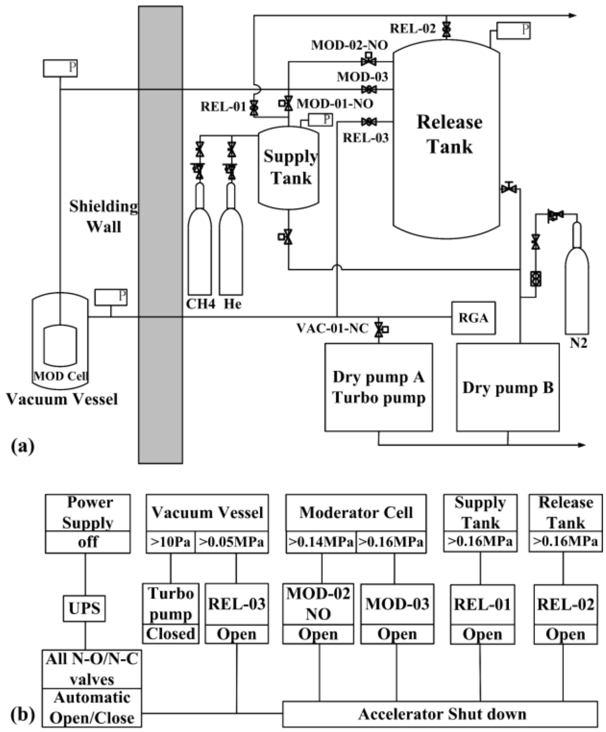

Fig. 3. (a) A schematic showing the gas handling system and the transport of methane gas into/out of the moderator cell (b) A schematic of the safety logic diagram for the TMR controls.

During operation, a supply of helium gas is maintained at a small positive pressure to prevent air leaking into the moderator or the gas-handling system. A release tank that is large enough to encapsulate all the gas from the solid methane at one atmosphere pressure is used as a reservoir, readily evacuated, for housing the methane from the moderator released unintentionally or purposely. The safety logic diagram is shown in Fig. 3b. A full safety analysis of various failure modes has been conducted. A critical fault event is an accidental leakage of air and/or methane gas into the vacuum vessel while the solid-methane moderator is in operation. Such happening will trigger the close off the pump lines to isolate the leak and to open the valve to the release tank. The gas in the release tank, diluted with nitrogen if necessary, can be evacuated through the facility's venting system. The vacuum vessel, which is designed to release the gases into release tank when specific accident scenario occurs, is the pressure boundary for the design basis accident. Even in the case of a rapture of the vacuum vessel, the force will be absorbed by the surrounding heavy shielding and will have no harmful consequence to personnel.

Keeping a constant volume of solid methane at a required temperature is a performance goal of the moderator system. However thermal fluctuations may not be avoided during a normal 2-week operational period. The control system includes a feedback loop so that an experimenter may opt to stop data acquisition automatically whenever a preset condition of the moderator stability is not met. Figure 4 shows the simulated neutron spectra at the downstream surface of the moderator with 18mm thickness which was optimized for CPHS case. The Monte Carlo simulations were performed using the MCNP code [9] and the scattering kernels of methane at 4, 10 and 20 K reported by Y.C. Shin et al.[10,11] under an ideal condition, i.e., assuming no thermal resistance across all interfaces. A shift of the spectral density towards lower energies is evident at the lower temperatures.

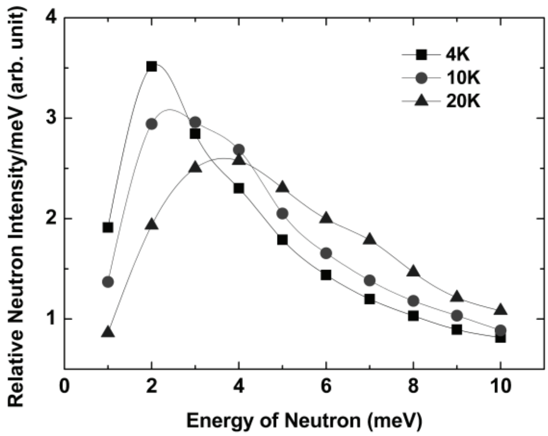

Fig. 4. The calculated neutron energy spectra at the moderator surface using the MCNP simulation code and the scattering kernel of methane at 4, 10, and 20 K.

4. Summary

We describe the configuration of the cold moderator with respect to the target and reflector environment of the CPHS neutron source. The introduction of methane gas from the supply tank to the moderator cell, the making of solid methane through a cooling procedure, and the scenarios of annealing and releasing the methane are considered. The proposed cryogenic equipment, gas-handling system, and the build-in monitoring and safety controls are adequate for a safe and reliable operation. Construction of a mock-up of the cryogenics plus moderator is currently under way. We plan to practice the cooling and solidification of an inert gas using a simplified gas-handling system before building the real system for the solid-methane moderator.

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